Port-Hamiltonian systems in modeling, simulation and control

Open Invited Track Code: ps3q8

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1 Abstract

It has been 30 years since the seminar paper "Port-Controlled Hamiltonian Systems: Modelling Origins and Systemtheoretic Properties" by B. Maschke and A. van der Schaft was presented in NOLCOS'92. Since then the framework, applications and related research community have steadily grown and expanded to encompass the modeling, control and simulation of non-linear systems, distributed parameter systems, irreversible thermodynamic systems, networked controlled systems, optimal control, spatial and time discretization, quantum systems, just to mention a few. Although Port-Hamiltonian systems are nowadays a well established formalism within the control community there are several open and challenging topics in regard to the complexity of the considered applications.

This open invited track aim to provide a well-balanced combination of recent theoretical results and their applications for mathematical modeling, structure-preserving approximation, model-based analysis, and observer and control design for lumped and distributed parameter systems using the framework of port-Hamiltonian systems. The track will bring together researchers from mathematics, engineering and the industrial community working in related fields or facing related control issues. The track will provide a forum for presenting and discussing the latest developments on theoretical, applied and computational aspects of the control of port-Hamiltonian systems by leading researchers. The

organizers aim to include contributions from both junior and senior faculty across different academic disciplines, i.e., electrical engineering, mechanical engineering, chemical engineering, applied mathematics, and representing different geographic regions. While all contributions will center around the track theme, they should cover a wide range of theoretical topics and applications that are of great interest to control researchers from academia and industry.

2 Association to Technical Committee

The track is handled by the TC 2.3 - Non-Linear Control Systems. The organizers stress that the track is not restricted to applications of the TC 2.3, in particular the track is closely related to the TC 2.6 - Distributed Parameter Systems.

3 Description of the Topic

The topics of this open invited track are the mathematical modeling, simulation, approximation, estimation and control of systems described by ordinary and partial differential equations using the framework of port-Hamiltonian systems.

Control theory based on Hamiltonian models has been proven to be a powerful tool for the control of electrical, mechanical and electro-mechanical systems. This theory is based on the principle of conservation of energy providing a clear physical interpretation of control design problem. Although traditionally Hamiltonian models arise from the Euler-Lagrange equations of motion, these have been extended to deal with network models of physical systems by using the concept of port-Hamiltonian systems. In networks models the system is considered as the interconnection of energy storing elements via basic physical interconnection laws (e.g. Newtons third law or Kirchhof's law) together with energy dissipating elements. Port-Hamiltonian system theory formalizes the basic interconnection laws together with the power-conserving elements by a geometric structure, and defines the Hamiltonian as the total energy stored in a system. The energy function determines not just the static behavior, but also, via the energy transfer between subsystems, its transient behavior. Thus, port-Hamiltonian systems have direct physical interpretation since they rely on energy balances, and are directly related with other network models, such as bond-graphs.

The framework of port-Hamiltonian system is particularly well adapted for the modeling, simulation and control of complex multi-physical systems. Multi-physical systems are system which exhibits dynamic behaviors generated by different physical phenomena. These systems encompass chemical processes, nano/micro-mechanical systems, smart materials, heat transfer processes, etc... In addition, many of these systems are modeled by partial differential equations coupled with ordinary differential equations, making the stability/stabilization analysis and the numerical methods used for simulations involved. A multi-physical system may usually be decomposed into a set of more simple interconnected subsystems. Hence, using an appropriate framework, they can studied and analyzed in a modular manner if the properties of its subsystems are understood. Since port-Hamiltonian systems define energy balances, and their inputs and outputs are conjugated in terms of the energy of the system, the framework has proven to be extremely powerful for the modeling of these systems, which is addressed in a constructive and systematic manner by interconnecting simple port-Hamiltonian systems.

From a simulation point of view, the differential geometric structure of port-Hamiltonian systems is common to finite and infinite dimensional systems. This transversal property permits to use the intrinsic Hamiltonian formulation for the proposition of finite element-methods, pseudo-spectral methods and other extensions, which result in finite-dimensional approximations which are again port-Hamiltonian systems. Since the approximated finite dimensional systems conserves the geometric structure, which is defined in terms of energy balances, the energetic properties of the infinite dimensional system are conserved when approximated. Geometric simulation algorithms may then be applied to the approximated system profiting the natural structure of the infinite dimensional system, preventing numerical dissipation and optimizing computer resource. Control schemes based on passivity based control techniques can then be applied to the approximated model in the same manner as for finite dimensional port-Hamiltonian systems.

In the case of boundary controlled linear systems defined on infinite dimensional spaces the existence of solutions, the stability and the design of stabilizing controllers can be tackled using linear semigroup theory and the associated abstract formulation based on unbounded input/output mappings. The extension of the Hamiltonian formulation to stabilizing control of boundary controlled systems defined on 1D linear spaces gave rise to the definition of boundary control port-Hamiltonian systems and allowed to parametrize, by simple matrix conditions, the boundary conditions that define a well-posed problem. Well-posedness and asymptotic and exponential stability have been investigated in open-loop and for static boundary feedback and linear and non-linear dynamic boundary control.

The framework of Hamiltonian systems has been extended to encompass simultaneously the conservation of energy and the irreversible entropy production by means of thermodynamic control systems defined by pseudo-gradient systems, metriplectic systems with one or two generating functions, non-linearly constrained Lagrangian systems and implicit Hamiltonian control systems, in the sense that they are defined on a submanifold of some embedding space, by control Hamiltonian systems defined on contact manifolds or their symplectization. Recently a formalism that threats irreversible thermodynamic system within the framework of port-Hamiltonian systems, allowing to model thermo-electro-mechanical systems in an unified manner have been proposed. This class of systems have been called Irreversible port-Hamiltonian systems and have been used to develop new thermodynamic consistent models and some first results on control synthesis for irreversible thermodynamic and coupled thermo-mechanical systems.

This open invited track aim to provide a well-balanced combination of recent theoretical results and their applications for mathematical modeling, structure-preserving approximation, model-based analysis, and observer and control design for lumped and distributed parameter systems using the framework of port-Hamiltonian systems. This open invited track aim at bringing together researchers from mathematics, engineering and industrial community working in related fields or facing related control issues. The proposed track will provide a forum for presenting and discussing the latest developments on theoretical, applied and computational aspects of the control of port-Hamiltonian systems by leading researchers. The organizers aim to include contributions from both junior and senior faculty across different academic disciplines, i.e., electrical engineering, mechanical engineering, chemical engineering, applied mathematics, and representing different geographic regions. While all contributions will center around the track theme, they should cover a wide range of theoretical topics and applications that are of great interest to control researchers from academia and industry.